(2)

b.s.

STORAGE RELIABILITY
OF
MISSILE MATERIEL PROGRAM

U.S. ARMY
MISSILE
RESEARCH
AND
DEVELOPMENT
COMMAND

Redstone Arsenal, Alabama 35809

STORAGE RELIABILITY SUMMARY REPORT

VOLUME IV

ORDNANCE DEVICES

LC-78-2 FEBRUARY 1978

PRODUCT ASSURANCE DIRECTORATE

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Storage Reliability Analysis Summary Report Volume IV Ordnance Devices		5. TYPE OF REPORT & PERIOD COVERED Final, June 1974 to Jan. 1978
		6. PERFORMING ORG. REPORT NUMBER LC-78-2, Vol. IV
7. AUTHOR(s) Dennis F. Malik		8. CONTRACT OR GRANT NUMBER(s) DAAK40-74-C-0853
9. PERFORMING ORGANIZATION NAME AND ADDRESS Raytheon Company, Equipment Division 3322 S. Memorial Parkway Huntsville, Alabama 35801		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Headquarters, U. S. Army Missile R&D Command, ATTN: DRDMI-QS, Redstone Arsenal, AL 35809		12. REPORT DATE Jan 1978
		13. NUMBER OF PAGES 63
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Reliability, Storage, Missile Materiel, Failure Rates, Failure Mechanisms, Operation, Ordnance, Solid Propellant, Rocket Motors, Gas Generators, Igniters, Safe & Arm Devices, Explosive Components

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report summarizes analyses on the non-operating reliability of missile ordnance devices. The analyses are part of a research program being conducted by the U. S. Army Missile R&D Command, Redstone Arsenal, AL. The objective of the program is the development of non-operating (storage) reliability prediction and assurance techniques for missile materiel. Included are analyses of solid propellant rocket motors, gas generators, igniters, safe and arm devices, and other explosive devices. Reliability models are

DD FORM 1473 1 JAN 73 EDITION OF 1 NOV 65 IS OBSOLETE

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. Abstract (continued)

developed for each component type. This report updates and replaces Report LC-76-2 dated May 1976.

6 2

STORAGE RELIABILITY OF MISSILE MATERIEL PROGRAM.

STORAGE RELIABILITY SUMMARY REPORT.
VOLUME IV.
ORDNANCE DEVICES.

LC-78-2

11 FEB [redacted] 78

14 LC-78-2-VOL-4

10

9 Final rept. Jun 74-Jan 78,

Prepared by: Dennis F. Malik

12 68 p.

PROJECT DIRECTOR
C. R. PROVENCE
PRODUCT ASSURANCE DIRECTORATE

HEADQUARTERS
U. S. ARMY MISSILE R&D COMMAND
REDSTONE ARSENAL, ALABAMA

15

IN COMPLIANCE WITH
CONTRACT NO. DAAK40-74-C-0853
DATED 4 JUNE 1974
DATA ITEM SEQUENCE NO. 3

RAYTHEON COMPANY
EQUIPMENT DIVISION

LIFE CYCLE ANALYSIS DEPARTMENT
HUNTSVILLE, ALABAMA

391 679

alf

ABSTRACT

This report summarizes analyses on the non-operating reliability of missile materiel. Long term non-operating data has been analyzed together with accelerated storage life test data. Reliability prediction models have been developed for various classes of devices.

This report is a result of a program whose objective is the development of non-operating (storage) reliability prediction and assurance techniques for missile materiel. The analysis results will be used by U. S. Army personnel and contractors in evaluating current missile programs and in the design of future missile systems.

The storage reliability research program consists of a country wide data survey and collection effort, accelerated testing, special test programs and development of a non-operating reliability data bank at the U. S. Army Missile R&D Command, Redstone Arsenal, Alabama. The Army plans a continuing effort to maintain the data bank and analysis reports.

For more information, contact:

Commander
U. S. Army Missile R&D Command
ATTN: DRDMI-QS , Mr. C. R. Provence
Building 4500
Redstone Arsenal, AL 35809
Autovon 746-3235
or (205) 876-3235

TABLE OF CONTENTS

VOLUME IV

SECTION NO.		PAGE NO.
1	INTRODUCTION	1-1
	1.1 Missile Reliability Considerations	1-1
	1.2 Storage Reliability Research Program	1-1
	1.3 Missile Environments	1-2
	1.4 System Level Analysis	1-4
	1.5 Limitations of Reliability Prediction	1-5
	1.6 Life Cycle Reliability Prediction Modeling	1-5
	1.7 Reliability Predictions During Early Design	1-8
	1.8 Summary of Report Contents	1-8
2	SOLID PROPELLANT MOTORS	2-1
	2.1 Effects of Prolonged Storage	2-2
	2.2 Reliability Prediction	2-3
	2.3 Data Analysis	2-5
	2.4 Conclusions and Recommendations	2-17
	2.5 Reference	2-18
3	IGNITERS AND SAFE & ARM DEVICES	3-1
	3.1 Failure Mechanisms	3-2
	3.2 Igniter and Safe & Arm Devices Reliability Models	3-3
	3.3 Data Analysis	3-6
	3.4 Conclusions and Recommendations	3-16
	3.5 Reference	3-17
4	SOLID PROPELLANT GAS GENERATORS	4-1
	4.1 Effects of Prolonged Storage	4-2
	4.2 Reliability Prediction	4-3
	4.3 Data Analysis	4-4
	4.4 Conclusions and Recommendations	4-9
	4.5 Reference	4-9
5	MISCELLANEOUS ORDNANCE DEVICES	5-1

TABLES

SECTION NO.		PAGE NO.
1-1	Report Contents	1-9
2.2-1	Propellant Unit Reliability (excludes Ignition Systems)	2-4
2.3-1	Solid Propellant Unit Storage Data	2-6
2.3-2	Storage Data by Major Classification	2-7
2.3-3	Ballistic Parameter Degradation with Age	2-8
2.3-4	Program A Specification Failures	2-9
2.3-5	Program D Specification Failures	2-11
2.3-6	Program E Specification Failures	2-12
2.3-7	Program G Surveillance Units	2-13
2.3-8	Program G Defects Identified in X-ray Inspection	2-13
2.3-9	Program G_{2B} Specification Failures	2-14
2.3-10	Specification Failure Modes	2-15
2.3-11	Propellant Unit Defect Summary	2-16
3.3-1	Igniter Storage Data	3-10
3.3-2	Igniter Storage Data by Major Classification	3-11
3.3-3	Safe and Arm Device Storage Data	3-13
3.3-4	Igniter Failure Modes	3-15
3.3-5	Safe and Arm Device Failure Modes	3-15
3.3-6	Other Unit Defects	3-16
4.2-1	Gas Generator Reliability (excludes Ignition Systems)	4-4
4.3-1	Gas Generator Storage Data	4-6
4.3-2	Failure Modes and Mechanisms	4-8
5-1	Storage Data on Miscellaneous Ordnance Devices	5-1

FIGURES

SECTION NO.		PAGE NO.
3.2-1	Igniter Reliability Prediction Model	3-4
3.2-2	Safe and Arm Device Reliability Prediction Model	3-5
3.2-3	Igniter Specification Reliability Prediction Model	3-7
3.2-4	Safe and Arm Device Specification Reliability Prediction Model	3-8
5-1	Miscellaneous Ordnance Device Failure Rates	5-2

1.0 INTRODUCTION

1.1 Missile Reliability Considerations

Materiel in the Army inventory must withstand long periods of storage and "launch ready" non-activated or dormant time as well as perform operationally in severe launch and flight environments. In addition to the stress of temperature soaks and aging, they must often endure the abuse of frequent transportation and handling and the climatic extremes of the forward area battlefield environment.

Missiles spend the majority of the time in this non-operating environment. In newer missile systems, complexity is increasing significantly, longer service lives are being required, and periodic maintenance and checkouts are being reduced. The combination of these factors places great importance on selecting missile materiels which are capable of performing reliably in each of the environments.

The inclusion of storage reliability requirements in the initial system specifications has also placed an importance on maintaining non-operating reliability prediction data for evaluating the design and mechanization of new systems.

1.2 Storage Reliability Research Program

An extensive effort is being conducted by the U. S. Army Missile Research & Development Command to provide detailed analyses of missile materiel and to generate reliability prediction data. A missile material reliability parts count prediction handbook, LC-78-1, has been developed and provides the current prediction data resulting from this effort.

This report is an update to report LC-76-2 dated May, 1976. It provides a summary of the analyses performed under the storage reliability research program and background information for the predictions in LC-78-1. Included are summaries of real time and test data, failure modes and mechanisms, and conclusions and recommendations resulting from analysis of the data. These recommendations include special design, packaging and product assurance data and information on specific part types and part construction.

For a number of the part types, detailed analysis reports are also available. These reports present details on part construction, failure modes and mechanisms, parameter drift and aging trends, applications, and other considerations for the selection of materiel and reliability prediction of missile systems.

The U. S. Army Missile Research & Development Command also maintains a Storage Reliability Data Bank. This data bank consists of a computerized data base with generic part storage reliability data and a storage reliability report library containing available research and test reports of non-operating reliability research efforts.

For the operational data contained in this report, the user should refer to the following sources: MIL-HDBK-217B, Military Standardization Handbook, Reliability Prediction of Electronic Equipment; Reliability Analysis Center (RAC) Microcircuit Failure Rates; RADC-TR-69-458, Revision to the Nonelectronic Reliability Handbook; and the Government-Industry Data Exchange Program (GIDEP) Summaries of Failure Rate Data.

1.3 Missile Environments

A missile system may be subjected to various modes of transportation and handling, temperature soaks, climatic extremes, and activated test time and "launch ready" time in addition to a controlled storage environment. Some studies have been performed on missile systems to measure these environments. A summary of several studies is presented in Report BR-7811, "The Environmental Conditions Experienced by Rockets and Missiles in Storage, Transit and Operations" prepared by the Raytheon Company, dated December 1973.

In this report, skin temperatures of missiles in containers were recorded in dump (or open) storage at a maximum of 165°F (74°C) and a minimum of -44°F (-42°C). In non-earth covered bunkers temperatures have been measured at a maximum of 116°F (47°C) to a minimum of -31°F (-35°C). In earth covered bunkers, temperatures have been measured at a maximum of 103°F (39°C) to a minimum of 23°F (-5°C).

Acceleration extremes during transportation have been measured for track, rail, aircraft and ship transportation. Up to 7 G's at 300 hertz have been measured on trucks; 1 G at 300 hertz by rail; 7 G's at 1100 hertz on aircraft; and 1 G at 70 hertz on shipboard.

Maximum shock stresses for truck transportation have been measured at 10 G's and by rail at 300 G's.

Although field data does not record these levels, where available, the type and approximate character of storage and transportation are identified and used to classify the devices.

1.4 System Level Analysis

The primary effort in the Storage Reliability Research Program is on analysis of the non-operating characteristics of parts. In the data collection effort, however, some data has been made available on system characteristics.

This data indicates that a reliability prediction for the system based on part level data will not accurately project maintenance actions if the missile is checked and maintained periodically. Factors contributing to this disparity include test equipment reliability, design problems, and general handling problems. In many cases, these problems are assigned to the system and not reflected in the part level analysis.

In general, a factor of 2 should be multiplied by the device failure rate to obtain the maintenance rate. Three system examples are described below:

1.4.1 System A

For system A, a check of 874 missiles in the field indicates 142 failed missiles. These failed missiles were taken to a maintenance facility. At the maintenance facility, no fault could be found in 51 of the missiles. Two missiles faults were corrected by adjustments. This left 89 failures which could be attributed to part failure. The parts were failure analyzed and the analysis indicated 19 failures to be a result of electrical overstress. These failures were designated design problems.

Therefore only 70 (49%) of the original 142 failures were designated as non-operating part failures.

1.4.2 System B

For system B, 26 missile failures were analyzed. Of these no fault was found in 2 missiles; adjustments were required for 2; external electrical overstress or handling damage was found in 10; a circuit design problem was assigned to 1, and component failures were assigned to 11.

1.4.3 Gyro Assemblies

An analysis of gyro assembly returns indicated that two thirds of the returns were attributed to design defects,

mishandling, conditions outside design requirements, and to erroneous attribution of system problems.

Therefore, only 33 percent of the returns were designated as non-operating part failures.

1.5 Limitations of Reliability Prediction

Practical limitations are placed in any reliability analysis effort in gathering and analyzing data. Field data is generated at various levels of detail and reported in varying manners. Often data on environments, applications, part classes and part construction are not available. Even more often, failure analyses are non-existant. Data on low use devices and new technology devices is also difficult to obtain. Finally in the storage environment, the very low occurrence of failures in many devices requires extensive storage time to generate any meaningful statistics.

These difficulties lead to prediction of conservative or pessimistic failure rates. The user may review the existing data in the backup analyses reports in any case where design or program decision is necessary.

1.6 Life Cycle Reliability Prediction Modeling

Developing missile reliability predictions requires several tasks. The first tasks include defining the system, its mission, environments and life cycle operation or deployment scenario.

The system and mission definitions provide the basis for constructing reliability success models. The modeling can incorporate reliability block diagrams, truth tables and logic diagrams. Descriptions of these methods are not included here but can be studied in detail in MIL-HDBK-217B or other texts listed in the bibliography.

After the reliability success modeling is completed, reliability life cycle prediction modeling for each block or unit in the success model is performed based on the definitions of the system environment and deployment scenario. This reliability life cycle modeling is based on a "wooden

round" concept in order to assess the missile's capability of performing in a no-maintenance environment. The general equation for this modeling is:

$$R_{LC} = R_{T/H} \times R_{STOR} \times R_{TEST} \times R_{LR/D} \times R_{LR/O} \times R_L \times R_F$$

where:

R_{LC} is the unit's life cycle reliability

$R_{T/H}$ is the unit's reliability during handling and transportation

R_{STOR} is the reliability during storage

R_{TEST} is the unit's reliability during check out and test

$R_{LR/D}$ is the unit's reliability during dormant launch ready time

$R_{LR/O}$ is the unit's reliability during operational (>10% electronic stress) launch ready time

R_L is the unit's reliability during powered launch and flight

R_F is the unit's reliability during unpowered flight

The extent of the data to date does not provide a capability of separately estimating the reliability of transportation and storage for missile materiel. Also data has indicated no difference between dormant (>0 and <10% electrical stress) and non-operating time. Therefore, the general equation can be simplified as follows:

$$R_{LC}(t) = R_{NO}(t_{NO}) \times R_O(t_O) \times R_L(t_L) \times R_F(T_F)$$

where: R_{NO} is the unit's reliability during transportation and handling, storage and dormant time (non-operating time)

t_{NO} is the sum of all non-operating and dormant time

R_O is the unit's reliability during checkout, test or system exercise during which components have electrical power applied (operating).

t_O is the sum of all operating time excluding launch and flight

R_L is the unit's reliability during powered launch and flight (Propulsion System Active)

t_L is the powered launch and flight time

R_F is the unit's reliability during unpowered flight

t_F is the unpowered flight time

t is the sum of t_{NO}, t_O, t_L and t_F

The values R_{NO}, R_O, R_F are calculated using several methods. The primary method is to assume exponential distributions as follows:

$$R_{NO}(t_{NO}) = e^{-\lambda_{NO}t_{NO}}$$

$$R_O(t_O) = e^{-\lambda_O t_O}$$

$$R_L(t_L) = e^{-\lambda_L t_L}$$

$$R_F(t_F) = e^{-\lambda_F t_F}$$

The failure rates λ_{NO}, λ_O, λ_L and λ_F are calculated from the models in the following sections. λ_{NO} is calculated from the non-operating failure rate models. The remaining failure rates are calculated from the operational failure rate models using the appropriate environmental adjustment factors. Each prediction model is based on part stress factors which may include part quality, complexity, construction, derating, and other characteristics of the device.

Other methods for calculating the reliability include wearout or aging reliability models and cyclic or one shot reliability models. For each of these cases, the device section will specify the method for calculating the reliability.

1.7 Reliability Predictions During Early Design

Frequently during early design phases, reliability predictions are required with an insufficient system definition to utilize the stress level failure rate models. Therefore, a "parts count" prediction technique has been prepared. It provides average base failure rates for various part types and provides K factors for various phases of the system deployment scenario to generate a first estimate of system reliability. This prediction is presented in Report LC-78-1.

1.8 Summary of Report Contents

The report is divided into five volumes which break out major component or part classifications: Volume I, Electrical and Electronic Devices; Volume II, Electromechanical Devices; Volume III, Hydraulic and Pneumatic Devices; Volume IV, Ordnance Devices; and Volume V, Optical and Electro Optical Devices. Table 1-1 provides a listing of the major part types included in each volume.

1.9 Extent of Volume IV Update

Only minor additions have been made to section 5. This volume has been included as part of the update to the entire LC-76-2 series.

TABLE 1-1. REPORT CONTENTS

		Detailed Rept: Number & Date
Volume I	**Electrical and Electronic Devices**	
Section		
2.0	Microelectronic Devices	LC-78-IC1, 1/78
3.0	Discrete Semiconductor Devices	-
4.0	Electronic Vacuum Tubes	LC-78-VT1, 1/78
5.0	Resistors	-
6.0	Capacitors	-
7.0	Inductive Devices	-
8.0	Crystals	-
9.0	Miscellaneous Electrical Devices	-
10.0	Connectors and Connections	-
11.0	Printed Wiring Boards	-
Volume II	**Electromechanical Devices**	
Section		
2.0	Gyros	LC-78-EM1, 2/78
3.0	Accelerometers	LC-78-EM2, 2/78
4.0	Switches	LC-78-EM4, 2/78
5.0	Relays	LC-78-EM3, 2/78
6.0	Electromechanical Rotating Devices	-
7.0	Miscellaenous Electromechanical Devices	-
Volume III	**Hydraulic and Pneumatic Devices**	
Section		
2.0	Accumulators	LC-76-HP2, 5/76
3.0	Actuators	LC-76-HP3, 5/76
4.0	Batteries	LC-78-B1, 2/78
5.0	Bearings	-
6.0	Compressors	-
7.0	Cylinders	-
8.0	Filters	-
9.0	Fittings/Connections	-
10.0	Gaskets	-
11.0	O-Rings	-
12.0	Pistons	-
13.0	Pumps	LC-76-HP4, 5/76
14.0	Regulators	-
15.0	Reservoirs	-
16.0	Valves	LC-76-HP1, 5/76
Volume IV	**Ordnance Devices**	
Section		
2.0	Solid Propellant Motors	LC-76-OR1, 5/76
3.0	Igniters and Safe & Arm Devices	LC-76-OR2, 5/76
4.0	Solid Propellant Gas Generators	LC-76-OR3, 5/76
5.0	Misc. Ordnance Devices	-
Volume V	**Optical and Electro Optical Devices**	

2.0 Solid Propellant Motors

A typical solid propellant unit has the following principal components: propellant, hardware and igniter. The hardware may include the motor body, combustion chamber, nozzle or mounting pads. The igniter is included in a separate analysis in Section 3.0.

Solid propellants are chemicals, in a plastic-like cake form, which produce hot, high pressure gases by means of a combustion process. There are several types of propellants. For modern missiles, these can be broken into two major classes: Composites and double base.

The main ingredients in a composite propellant are a fuel and an oxidizer. Often these consist of crystalline, finely ground oxidizers dispersed in a matrix of a fuel compound.

The double base propellant contains unstable chemical compounds, such as nitrocellulose or nitroglycerin, which are capable of combustion in the absence of all other material. This type sometimes called homogeneous propellants contains no crystals, but uses chemical fuel that contains enough chemically bonded oxidizer materiel to sustain combustion.

Most of the solid propellants contain from four to eight different chemicals. In addition to the principal ingredients (fuel and oxidizer), small percentages of additives are used to control the physical and chemical properties of the solid propellant. Additives have been used for the following typical purposes: 1) accelerate or decelerate the burning rate (catalyst); 2) increase chemical stability to avoid deterioration during storage; 3) control various processing properties of propellant during fabrication (curing time, fluidity for casting, wetting agent, etc.); 4) control radiation absorption properties of burning propellant; 5) increase physical strength and decrease elastic deformation; 6) minimize temperature sensitivity.

2.1 Effects of Prolonged Storage

2.1.1 Composite Propellant

Mechanical stresses from transportation and temperature extremes and repeated temperature stresses can have deteriorating effects on propellant properties.

Cracks, voids, and tearing in the propellant materiel are a major result of these environments. The primary cause for these defects in composite propellants are: the difference in the thermal expansion between the propellant grain and the motor body and inhibitors; and the temperature stress at the oxidizer-filler interface.

At low temperature, physical changes cause propellants to become hard and brittle, and thus very susceptible to cracking due to shock loads. When the propellant is in this brittle condition, expansion or other physical changes which occur as the temperature rises may cause cracking. The hardening of a case-bonded charge at low temperature may result in the charge coming away from the case. The repeated expansion and contraction with cyclic temperature changes can cause deterioration of the charge.

The deterioration may get worse with increasing duration of exposure to a given set of ambient conditions, and may be accelerated at wider temperature extremes.

Tensile stress at the oxidizer-filler interface in composite propellants may lead to the formation of voids around the oxidizer particles. Once void formation has started, it propagates to the vicinity of neighboring particles to produce a band or region of these failures.

At high temperatures, chemical and physical changes in the propellant may cause a serious reduction in the value of the coefficient of elasticity. The inhibitor may also deeriorate at high temperature. When the motor is fired, the charge may deform excessively or portions may even break loose. This can increase the burning area and pressure causing out of spec, thrust and burn-times or even cause the motor to burst. Portions of propellant which break loose can also

block the motor nozzle and result in a catastrophic failure.

Humidity can sometimes accelerate this deterioration. Motors are normally provided with humidity sealing to prevent ingress of moisture to the propellant.

Cracks in the propellant will increase the burning surface areas, which increases pressure and causes out of specification conditions.

2.1.2 Double-Base Propellant

Double-base propellants are prone to the same types of deterioration as described for composite propellants with the exception of the void formation at the oxidizer-filler interface. The double-base propellant is a homogeneous mixture and does not have the solid oxidizers in the grain.

However, in double-base propellants, nitrocellulose decomposes slowly but continuously, releasing oxides of nitrogen. The rate of decomposition is accelerated by the presence of these oxides. Certain materiels called "stabilizers" can combine chemically with the oxides and remove them. The stabilizer does not prevent decomposition but retards the rate after it has commenced. This decomposition can create grain defects in the form of gas bubbles or cracks.

2.1.3 Hardware

Corrosion has been reported as a major effect of storage. Seals at the igniter and the nozzle have deteriorated from corrosion. Movable fin mechanisms have corroded preventing proper operation of these devices. Also handling of the missile has resulted in damage and contamination of these control mechanisms.

2.2 Reliability Prediction

The data collected to data shows no solid propellant motor failure which would have failed the mission requirements. Since the data indicates that the motors are definitely deteriorating with age, a failure rate prediction based on the number of hours in storage would be meaningless. Therefore, reliabilities based on binomial confidence levels for the number of successes during the fifth and tenth year were

calculated. Table 2.2-1 gives the reliabilities for confidence levels of 50% and 90%.

The variation in the reliabilities in Table 2.2-1 is strictly a function of the number of data samples available for each classification and the predictions are considered conservative. The measured reliability for all the units was 1.000.

Based on each program analysis, the recommended service lives for the propellant units were 11 to 14 years for the double base, single thrust units; 9 to 11 years for the double base, dual thrust units; 8 to 11 years for the composite, single thrust units; and 11 years for the composite, dual thrust unit.

TABLE 2.2-1. PROPELLANT UNIT RELIABILITY
(excludes Ignition System)

Classification	Reliability: 50% Confidence 5 Yrs.	50% Confidence 10 Yrs.	90% Confidence 5 Yrs.	90% Confidence 10 Yrs.
Double Base, Single Thrust	.930	.925	.795	.790
Double Base, Dual Thrust	.952	*	.850	*
Composite, Single Thrust	.992	.924	.972	.790
Composite, Dual Thrust	.944	*	.827	*
All Motors	.994	.964	.981	.890

*No data available at 10 years.

2.3 Data Analysis

Detailed data from surveillance of eight missile programs has been collected and analyzed. Out of 13,636,700 hours of unit storage, ballistic data from 326 static firings indicated 43 failures to meet original acceptance specifications. No catastrophic failures were reported. Analysis of the 43 specification failures by program personnel indicated that in each case, the missile was capable (if only marginally) of performing its intended mission. Therefore, no solid propellant unit was considered failed. Analysis of motor igniters is included in Section 3.0.

2.3.1 Data Classification

Table 2.3-1 summarizes the data on the solid propellant units. Four programs (A, B, C and D) utilized double base propellants while the remainder used composite propellants. Program A and B propellants were extruded; programs C, D, E, F_1 and G_1 were cast; and programs F_2, G_2 and H were case bonded. Three programs (C, D and E) used the propellants in a dual thrust configuration.

The subscripts 1 and 2 on programs F and G refer to different propellant configurations for the same missile program.

For three programs (E, G_2 and H), the data was broken out by manufacturer (designated A and B). In all three cases, a definite difference in propellant characteristics was identified between the different manufacturers. Also in a few cases, differences were identified between propellant lots from the same manufacturer.

These statistics are further summarized in Table 2.3-2 by four major classifications: Double base propellant (single and dual thrust); and composite propellants (single and dual thrust).

Between these four major classifications, the average age of the units is relatively close except for the dual thrust composite motors which are about two years younger than the rest.

For both double base and composite propellants, the dual thrust motors show a significantly higher percent of specification failures than the single thrust motors. In both cases, the dual thrust motors are also the largest motors in the sample.

TABLE 2.3-1. SOLID PROPELLANT UNIT STORAGE DATA

PROGRAM	PROPELLANT	TI*	NO. OF UNITS	STORAGE HOURS	ACCEP. SPEC. FAILURES	MISSION FAILURES	UNIT AGE (MONTHS)
A	Single Thrust; Double Base, Extruded	1	106	5,377,180	12	0	19 to 169
B	Single Thrust; Double Base, Extruded	2	17	471,580	1	0	28 to 52
C	Dual Thrust, Double Base, Cast	3	4	70,080	2	0	96
D	Dual Thrust, Double Base, Cast	3	26	1,138,800	18	0	12 to 168
E	Dual Thrust, Composition, Cast	3	(A) 31 (B) 7	822,710 218,270	5 0	0 0	11 to 80 36 to 52
F_1	Single Thrust, Composition, Cast	2	19	664,300	0	0	26 to 75
G_1	Single Thrust, Composition, Cast	2	16	689,850	0	0	50 to 73
F_2	Single Thrust, Composition, Case Bonded	2	4	105,120	0	0	32 to 40
G_2	Single Thrust, Composition Case Bonded	2	(A) 17 (B) 32	494,210 1,297,940	0 4	0 0	9 to 61 32 to 68
H	Single Thrust, Composition, Case Bonded	2	(A) 24 (B) 23	1,156,320 1,130,040	1 0	0 0	12 to 72 12 to 72

* Total Impulse Range:
1: <10,000 lb-sec
2: 10,000 to 50,000 lb-sec
3: >50,000 lb-sec

TABLE 2.3-2. STORAGE DATA BY MAJOR CLASSIFICATION

Classification	No. of Units	Unit Storage Hours	Specification Failures		Average Age of Units
			No.	Percent	
Double Base					
Single Thrust	123	5,848,760	13	10.6	65 months
Dual Thrust	30	1,208,808	20	66.7	55 months
Composite					
Single Thrust	135	5,537,780	5	3.7	56 months
Dual Thrust	38	1,040,980	5	13.2	37 months

The double base propellants overall show a significantly higher percent of specification failures as compared to the composite propellants.

2.3.2 Degradation with Age

Six of the eight missile programs projected degradation of ballistic parameters with age. Table 2.3-3 shows the average percentage change in 10 years for each ballistic parameter for the four classes of motors analyzed. Also shown are maximum and minimum changes observed. Ballistic parameters are defined as follows:

a) Action Time - time interval between reaching a specified initial chamber pressure and reaching that same pressure as the burn decays.

b) Maximum Pressure - highest pressure at any point on the pressure-time trace.

c) Maximum Thrust - highest thrust value at any point on the thrust-time trace.

d) Average Thrust - value obtained by dividing the area under the thrust-time trace by the action time.

e) Total Impulse - area under the entire thrust-time curve generally expressed in pound-seconds.

TABLE 2.3-3. BALLISTIC PARAMETER DEGRADATION WITH AGE

CLASSIFICATION/PARAMETER	Average % Change for 10 Years	Maximum Change	Minimum Change
Double Base, Single Thrust			
Action Time	+15.0	+20.0 -4.0	-0.1
Total Impulse	- 2.0	+ 1.7 - 5.1	*
Double Base, Dual Thrust			
Action Time	+25.0	+30.0	+4.4
Maximum Pressure	-10.0	-19.4	-2.3
Maximum Thrust	-11.0	-20.8	-3.8
Total Impulse	-16.0	-30.0	-0.6
Composite, Single Thrust			
Action Time	*	+22.3 -19.7	*
Maximum Pressure	*	+5.0 -27.5	-0.3
Maximum Thrust	+1.6	+22.3 -5.2	+0.1
Average Thrust	+0.4	+24.5 -14.5	+0.3
Total Impulse	*	+1.9 -2.3	*
Composite, Dual Thrust			
Action Time	-0.5	+3.3 -8.5	*
Maximum Pressure	+3.7	+7.0 -2.9	+0.9
Average Thrust	-0.3	+11.2 -7.0	+0.5
Total Impulse	-0.8	+0.9 -1.5	+0.1

*Value either zero or less than 0.1%.

2.3.3 Handling and Environment Problems

Besides the general aging characteristics of the materiels described earlier, several problems were noted in the field environment. These included corrosion, particularly important at the control surfaces, contaminated or dirty control mechanisms, and bent or damaged surfaces.

2.3.4 Program Data

Summarized data on each of the missile programs for which surveillance data was available is included in the following sections.

2.3.4.1 Program A

The solid propellant for program A is an extruded double base grain single thrust configuration.

The surveillance included 148 motors. Thirty units had been stored in a humid, salt water environment for ten years. Severe rust and corrosion at the contact bond, nozzle and fin assembly resulted in a decision to destrcy these units.

Tests of propellant grains from eight motors indicated a general trend toward increasing tensile strength and decreasing elongation with age.

Static firing tests of 106 motors were conducted. These included 67 motors, 2 to 4 years old; 34, 10 to 12 years old; and 6 prototypes, 14 years old. Twelve specification failures were noted and are described in Table 2.3-4.

TABLE 2.3-4. PROGRAM A SPECIFICATION FAILURES

Age in Months	Preconditioning Temperature - °F	Failure
32	165	Failed minimum total impulse
32, 33, 33, 35, 37 42, 42, 114, 116	165	Exceeded maximum action time
144	-30	Failed minimum ignition delay
162	-30	Exceeded maximum ignition delay

2.3.4.2 Program B

The solid propellant for program B is an extruded double base grain in a single thrust configuration.

The motor required two major reworks during its deployment - the first corrected a fin-pad weld cracking problem and the second delt with a grain shrinkage problem.

Before this rework, several motors had failed due to high pressure after conditioning at high temperature. It was probable that the malfunctions were caused by reduced mechanical properties which allowed grain collapse and subsequent nozzle blockage. No serious problem has been reported with the reworked grains.

Sixteen motors were tested in a surveillance test. Motor ages were nine to ten years; age since rework was three to four years. One motor, age 106 mo. (42 mo. since rework), exceeded the maximum pressure specification. The amount exceeded was very small and would not have caused an error in the missiles trajectory.

No trends in ballistic parameters could be estimated due to the rework condition of the motors since acceptance.

2.3.4.3 Program C

The solid propellant for program C is a cast double base grain in a dual thrust configuration.

The motor required a major rework during its deployment to overcome a drop in delivered impulse due to chemical aging. As a corrective action, metal was removed from the nozzle to decrease the units weight.

Visual and radiographic inspection of four motors (ages 96 months) revealed slight cracks along the axial spars. Two had received the rework as described; two had not.

Static firings of the four boosters were conducted. The two motors which had been reworked exceeded the maximum action time specification.

An insufficient sample size was available to develop trends in ballistic parameters.

2.3.4.4 Program D

The solid propellant for program D is a cast, double base grain in a dual thrust configuration.

The surveillance consisted of an accelerated test program which approximately doubles the aging time of the propellants. One accelerated storage cycle included 3 weeks at 70°F, 16 weeks at 100°F, 3 weeks at 70°F and 4 weeks at 40°F.

A total of twenty-six units were static fired over a period of 7 years: 4 each at 6, 12, 18, 24 and 36 months, and 2 each at 48, 66 and 84 months.

A total of eighteen units failed one or more specifications as indicated in Table 2.3-5.

TABLE 2.3-5. PROGRAM D SPECIFICATION FAILURES

Age in Months Actual (Extrapolated)	Preconditioning Temperature - °F	Failure
6 (12)	-30	Exceeded maximum action time
12 (24)	-20	
6 (12); 12 (24); 12 (24);	-30	Exceeded maximum action time and failed minimum total impulse
18 (36); 18 (36)	-30	
24 (48); 24 (48); 36 (72); 36 (72); 48 (96); 66 (132); 84 (168)	10	
24 (48); 24 (48); 36 (72); 36 (72)	120	Failed minimum total impulse

Definite aging trends in ballistic performance were indicated with action time increasing with age and maximum pressure, maximum thrust and total impulse decreasing with age. In all but one case, the trend appears to level out at from 1 to 8 years.

2.3.4.5 Program E

The solid propellant for program E is a cast, composite grain in a dual thrust configuration.

Twenty-eight units were involved in surveillance testing ranging in age from 1 to 7 years with the average age being 4-1/4 years.

Static firings of 19 units resulted in 5 failures to meet acceptance specifications as shown in Table 2.3-6.

TABLE 2.3-6 PROGRAM E SPECIFICATION FAILURES

Age in Months	Preconditioning Temperature - °F	Failure
30; 51; 63; 75	20°F	Failed minimum total thrust
36	130°F	Exceeded maximum pressure

Trends indicate that the booster impulse has increased with age while sustainer and total impulse have decreased. The trend in decreasing total impulse appears to level out at from 3 to 6 years.

2.3.4.6 Program F

The solid propellant for program F is a cast, composition grain with a single thrust capability. Two propellant configurations were monitored in the surveillance tests. Configuration one is a free-standing, cartridge-type grain consisting of a cylindrical tube cast on an integral, fiberglass reinforced support tube. Configuration two is a case bonded grain with a five star grain pattern. Both propellant configurations are ammonium perchlorate and aluminum composites.

External examination of 23 motors revealed minor cases of rust and dirty fin slots. Radiographic inspection revealed two motors with separations at the forward end cap exceeding 3/8 inch, and four motors with small cracks in the aft case phenolic insulator.

Nineteen configuration one motors ranging in age from 2 to 6 years with an average age of 4 years and four configuration two motors, average age 3 years, were static fired.

All ballistic parameters were within specification. Insufficient data was available to develop trends.

2.3.4.7 Program G

The two solid propellant configurations for program G are identical to those for program F. Table 2.3-7 gives statistics on the units involves in the surveillance.

TABLE 2.3-7. PROGRAM G SURVEILLANCE UNITS

Configuration	Manufacturer	Qty.	Age Range	Average Age
1	-	16	4-6 yrs.	5 yrs.
2	A	17	1-5 yrs.	3 1/3 yrs.
2	B	32	3-6 yrs.	4 1/2 yrs.

The defects indicated in Table 2.3-8 were identified in the X-ray inspection.

Of the motors static fired, which had identified defects in the X-ray inspection, only two failed to meet acceptance specifications.

TABLE 2.3-8. PROGRAM G DEFECTS IDENTIFIED IN X-RAY INSPECTION

Configuration	Manufacturer	No. of Motors Defective	No. Static Fired	No. Failed Specs.	Defect
1	-	1	1	0	Crack in aft phenolic region near weather seal
1	-	1	1	0	End cap severely cracked
2	A	6	2	0	Voids (up to 5/16 in. max) and/or porosity in the grains
2	B	2	1	0	Small voids throughout grain
2	B	3	0	0	Aft end boot to case separations
2	B	3	3	2	Abnormally thick regions in liner

Results of static firings of the configuration 1 test motors and the configuration 2 test motors for manufacturer A indicated no specification failures. Four specification failures for samples from manufacturer B, configuration 2 were identified and are shown in Table 2.3-9.

TABLE 2.3-9. PROGRAM G_{2B} SPECIFICATION FAILURES

Age in Months	Preconditioning Temperature-°F	Failure
66	-65	Exceeded maximum average thrust
48, 61	160	Failed minimum average thrust
66	160	Exceeded maximum average thrust and maximum thrust specifications.

Trends in ballistic aging characteristics were combined for programs F and G. The general trend is toward decreasing action time and total impulse and increasing max thrust and max pressure.

2.3.4.8 Program H

The surveillance consisted of an accelerated test program identical to that described for program D. A total of 47 units were static fired over a period of six years: 4 at 6 months; 8 at 12 months; 3 at 18 months; 6 at 24 months; 4 at 30 months; 8 at 36 months; 4 at 48 months; 6 at 60 months; and 4 at 72 months.

X-ray inspection of 35 motors indciated an area of unbondedness between the end initiator and the motor tube on one motor.

Eighteen motors were static fired successfully.

Twelve motors were put through environmental testing before static firing.

Mechanical properties tests of propellant samples indicated the tensile strength remains relatively constant with age where as elongation at rupture decreases with age.

Aging trends in ballistic parameters were estimated for the non-environmentally tested motors and indicated an increasing max thrust with age.

2.3.5 Failure Modes and Mechanisms

Table 2.3-10 summarizes the failure modes exhibited during the static firing tests. The failure definition is failure to be within original acceptance specifications.

2.3.5.1 Double Base Propellant

For double base propellant 76% of the failures exceeded the maximum action time specification and 57% failed the minimum total impulse specification. (There is overlap in the failures since some units failed more than one specification.) Three other failures appeared to be random occurrences.

In double base propellants the trend toward increasing action time and decreasing performance parameters can be attributed to the general decomposition of the propellant ingredients with age. Although the major propellant ingredients are inherently unstable, the stabilizers added to the propellant mix generally prevent rapid decomposition and maintain ballistic parameters for the life of the missile.

TABLE 2.3-10. SPECIFICATION FAILURE MODES

Single Thrust, Double Base

9 units exceeded maximum action time specification
1 unit failed minimum total impulse specification
1 unit exceeded maximum ignition delay specification
1 unit failed minimum ignition delay specification
1 unit exceeded maximum thrust specification

Dual Thrust, Double Base

4 units exceeded maximum action time specification
12 units exceeded maximum action time and failed minimum total impulse specifications
4 units failed minimum total impulse specification

Single Thrust, Composite

1 unit failed minimum average thrust specification
2 units exceeded maximum average thrust specification
1 unit exceeded maximum thrust specification
1 unit exceeded maximum ignition delay specification

Dual Thrust, Composite

4 units failed minimum total impulse specification
1 unit exceeded maximum pressure specification

2.3.5.2 Composite Propellants

For composite propellants, the failure modes summarized in Table 2.3-10 represent a relatively small sample and are fairly random. In general, they follow the trend toward decreasing action time and total impulse and increasing maximum thrust and pressure.

These trends can be generally attributed to cracking, voiding, or tearing in the propellant grain; separations between grain and body or inhibitor; and changes in the elasticity coefficient of the propellant. In all these cases, the surface area can be increased resulting in a shorter burn time, higher pressure and thrust and lower total impulse. With the small number of specification failures, these trends do not appear to significantly affect the missiles useful life.

2.3.6 Other Propellant Defects Identified

In addition to the failure modes identified from static firing, other defects in the propellant units were identified in the surveillance tests. These are summarized in Table 2.3-11.

TABLE 2.3-11. PROPELLANT UNIT DEFECTS SUMMARY

DEFECT	TEST
Single Thrust, Double Base Motor	
Fin Pad weld cracking (reworked)	Visual
Grain Shrinkage (reworked)	Visual
Hot gas seal at igniter post failure (reworked)	Static Firing
Severe rust and corrosion after 10 years in humid, salt storage environment	Visual
Missing O-ring	X-Ray
Increasing Tensile Strength, decreasing elongation	Mechanical
Dual Thrust, Double Base Motor	
Stabilizer decrease with age	Chemical
Propellant brittle with age	Mechanical
Burning rate near inhibitor lower	Strand Burn

TABLE 2.3-11. PROPELLANT UNIT DEFECTS SUMMARY
(cont'd)

DEFECT	TEST
Single Thrust, Composite Motor	
Unbondedness between: Inhibitor and motor tube; propellant and liner; and forward end cap and propellant	X-Ray
Cracking: Aft phenolic region; end cap; insulator	X-Ray
Uneven liners and liners with abnormally thick regions	Visual & X-Ray
Increasing elongation at rupture	Mechanical
Slipped cushion in transportation container	Visual
Improper electrical grounds in transportation container	Visual
Voids and/or porosity in grain	X-Ray
Dirty and corroded fin slots	Visual
Dual Thrust, Composite Motor	
Light Corrosion	Visual
Voids in propellant	X-Ray
Combustion instability: loose insulation; retained weather seal	Static Firing
Cracked grains (MOD in Grain pattern)	X-Ray

2.4 Conclusions and Recommendations

The data analyzed for solid propellant motors indicated no motor failures which would have failed the mission requirements. Until more data is collected, it is recommended that the following reliability prediction be used for solid propellant units:

5 Year Reliability:	.994 at 50% confidence
	.981 at 90% confidence
10 Year Reliability:	.964 at 50% confidence
	.890 at 90% confidence

Igniters are not included in this prediction. See Section 3.0 for analysis of igniters.

The data also indicated that the composite propellant shows significantly less deterioration with age than the double base propellant. Therefore, composite propellants should be considered for all applications.

Dual thrust motors were indicated in the data to undergo more deterioration with age than single thrust motors.

Missile systems design should compensate for changes in motor performance.

Surveillance programs have proven to be invaluable aids to detect excessive aging of propellants and to initiate early correction for maximum system life.

2.5 Reference

The information in Section 2 is a summary of document number LC-76-OR1, "Solid Propellant Motor Analysis," dated May 1976. Refer to that document for details of data collection and analysis as well as technical descriptions of solid propellant motors.

3.0 Igniters and Safe and Arm Devices

Igniters are rapid burning devices which develop a sudden evolution of heat and gas and in some cases hot particles. The gas produces a sharp pressure peak which may be of greater magnitude than the operating pressure of the rocket motor or gas generator.

The igniters are initiated by means of an electric squib. At least two squibs are used per igniter for reliability. Basically, the squib consists of a body in which are imbedded two electric leads, a bridge wire which shorts the leads and is heated by the passage of an electric current, and a heat-sensitive materiel normally applied as a bead to the bridge wire. A small booster charge of black powder or other pyrotechnic mixture may be part of the squib for initiation of the igniter. This charge and burnout wire are encased in a metal cup crimped tightly to prevent contamination. The squibs are designed not to fire until a certain critical electrical energy is applied. This allows continuity testing without danger of premature ignition. It also prevents the squib from firing from stray induced currents from electronic gear or power lines in the area.

Two basic types of igniters are used in current missile systems: pyrotechnic and pyrogen igniters.

Pyrotechnic mixtures range from black powder with powdered metals to metal oxidants. A black powder/magnesium mixture is used in several igniters for which data has been collected. Metal oxidants have become replacements for black powder in some of the newer ignition systems. The most common mixtures contain magnesium, aluminum or boron powder and potassium nitrate or perchlorate. Granular mixtures usually react too rapidly, so the mixtures are generally pressed into pellets.

The igniter container has been made of tin or plastic. For large rockets, a perforated tube may be used to contain the pyrotechnic. It may be half or more of the length of

motor grain. In other designs, a plastic or metal can is used. The cover of the can ruptures at the initiation and the hot gases are released to the propellant grain.

The pyrogen igniter is a small rocket motor used to ignite the main motor. The design used for pyrogens, in general, similar to the main charge. The exhaust from the pyrogen is directed via a nozzle into the center performation of the main motor; usually from the forward end. Fast burning propellants are used at moderately high pressures to obtain a high mass discharge rate. For very large motors,the use of a pyrogen provides a better method of ignition.

The pyrogen is initiated by squibs and a pyrotechnic primer. Igniter charges generally consist of double base propellant materiels such as nitrocellulose and nitroglycerin.

The safe and arm (S&A) device electrically isolates the igniter to prevent premature ignition of the propellant motor or gas generator and to allow for electrical testing of the ignition circuitry. In some cases, the S&A device also mechanically isolates the initiator (squibs and primer mixture) from the pyrotechnic mixture or pyrogen motor.

Data has been collected on three types of S&A devices: inertial rotary type; manual rotary type; and motor driven rotary type.

The inertial S&A device is used in the upper stage of a multistage missile. Acceleration of the booster stage provides the energy to activate the inertial device.

The manual rotary S&A device is activated for small missiles before or after it is loaded into the launcher.

The motor driven rotary S&A device is used for remote actuation.

3.1 Failure Mechanisms

3.1.1 Igniters

The igniter generally experiences two categories of failure mechanisms. The first category is failures associated with the initiator, including failure of the lead wires and bridge wires in the squib. These failures usually

lead to non-ignition. The failures may be a result of quality defects, handling damage, contamination or corrosion.

The second category is an aging characteristic in which pyrotechnic and/or propellant mixtures deteriorate with age. This deterioration generally results in a decrease in igniter pressure and long ignition delays. The deterioration may progress to a point of non-ignition.

The degradation of the ordnance materials with age may result from several causes. Package leaks caused by inadequate seals or cracked cases can allow moisture to deteriorate the materiels. In addition, pyrogen propellants are subject to long term decomposition. This decomposition is slowed by the addition of stabilizers in the propellant mix.

3.1.2 Safe and Arm Devices

The S&A device exhibit failure mechanisms such as those for switches in other applications. These include deformed, broken or loose contacts and contact springs, defective welds and/or solder joints, contamination, contact corrosion, and defective or damaged lead wires.

Possible aging mechanisms have also been noted which degrade arming times. This degradation is caused by corrosion of sliding surfaces and degradation of seals and packing.

3.2 Igniter and Safe and Arm Devices Reliability Models

Analysis of the data indicated that the reliability of these devices has two components; a time dependent component and a random component. A reliability model defined as a function of both characteristics was developed.

$$R(t)_{\text{S\&A device}} = [R(t)_{\text{aging}}] \times [R(t)_{\text{random}}]$$

Figure 3.2-1 gives the igniter reliability prediction model. Figure 3.2-2 gives the safe and arm device model.

For programs which periodically test devices and replace them when specification failures exist, the replacement rate will be higher than that noted in the reliability calculations.

FIGURE 3.2-1. IGNITER RELIABILITY PREDICTION MODEL

$$R(t)_{igniter} = [R(t)_{aging}] \times [R(t)_{random}]$$

$$R(t)_{random} = \exp(-\lambda t)$$

Classification	R(t) Aging				λ	
	50% confidence		90% confidence		50% Confidence	90% Confidence
	5 yrs.	10 yrs.	5 yrs.	10 yrs.		
Solid Rocket Motor Pyrogen Igniters	.998	.986	.994	.954	65×10^{-9}	129×10^{-9}
Solid Rocket Motor Pyrotechnic Igniters	.995	.991	.984	.969	65×10^{-9}	129×10^{-9}
Gas Generator Igniters	.997	.979	.991	.934	65×10^{-9}	129×10^{-9}

FIGURE 3.2-2. SAFE AND ARM DEVICE RELIABILITY PREDICTION MODEL

$$R(t)_{S\&A\ device} = [R(t)_{aging}] \times [R(t)_{random}]$$

$$R(t)_{random} = \exp(-\lambda t)$$

	R(t) aging				λ	
	50% confidence		90% confidence		50% confidence	90% confidence
Classification	5 yr.	10 yr.	5 yr.	10 yr.		
Inertial S&A	.992	.976	.975	.923	134×10^{-9}	207×10^{-9}
Manual S&A	1.000	1.000	1.000	1.000	134×10^{-9}	207×10^{-9}
Motor Driven S&A	.964	.954*	.948	.912*	134×10^{-9}	207×10^{-9}

*Extrapolated from 1 through 8 year data.

The models for specification reliability for igniters and safe and arm devices are shown in Figures 3.2-3 and 3.2-4 respectively.

3.3 Data Analysis

Data from surveillance of fourteen missile programs has been collected and analyzed.

Approximately 45 million unit storage hours of solid propellant motor igniters indicated 4 failures which would have failed to ignite the motor in 452 static firings and 952 missile firings. Of this data, 15 million unit storage hours with 295 static firings contained ballistic parametric data. Five specification failures were indicated, 3 of which would not have failed the mission requirements.

Approximately 17 million unit storage hours of gas generator igniters indicated no failures which would have failed to ignite the gas generator in 332 static firings. Of this data, 14 million unit storage hours with 274 static firings contained ballistic parametric data. Six specification failures were reported, none of which would have failed the mission requirements.

Approximately 75 million unit storage hours of safe and arm devices indicated 45 failures which would have failed the motor ignition requirements in 2212 unit tests. Ten units failed to arm and 35 units armed in insufficient time to meet mission requirements. Of this data, 65 million unit storage hours with 2016 unit tests, recorded arming times and circuit resistances. One hundred forty seven specification failures were indicated. These failures occurred on motor driven rotary safe and arm switches. Thirty five of these specification failures would have failed the mission requirements.

FIGURE 3.2-3. IGNITER SPECIFICATION RELIABILITY PREDICTION MODEL

$$R(t)_{igniter} = [R(t)_{aging}] \times [R(t)_{random}]$$

$$R(t)_{random} = \exp(-\lambda t)$$

Classification	R(t) aging				λ	
	50% Confidence		90% Confidence		50% confidence	90% confidence
	5 yr.	10 yr.	5 yr.	10 yr.		
Solid Rocket Motor Pyrogen Igniters	.987	*	.960	*	65×10^{-9}	129×10^{-9}
Solid Rocket Motor Pyrotechnic Igniters	.982	.975	.958	.942	65×10^{-9}	129×10^{-9}
Gas Generator Igniters	.964	.935	.950	.870	65×10^{-9}	129×10^{-9}

*No data at 10 years.

FIGURE 3.2-4. SAFE & ARM DEVICE SPECIFICATION RELIABILITY PREDICTION MODEL

$$R(t)_{S\&A\ device} = [R(t)_{aging}] \times [R(t)_{random}]$$

$$R(t)_{random} = \exp(-\lambda t)$$

	R(t) aging				λ	
	50% Confidence		90% Confidence		50% Confidence	90% Confidence
Classification	5 yrs.	10 yrs.	5 yrs.	10 yrs.		
Inertial S&A Device	.950	.840	.905	.730	134×10^{-9}	207×10^{-9}
Manual S&A Device	1.000	1.000	1.000	1.000	134×10^{-9}	207×10^{-9}
Motor Driven S&A Device	.890	.809*	.880	.800*	134×10^{-9}	207×10^{-9}

*Extrapolated from 1 through 8 year data.

3.3.1 Data Classification

3.3.1.1 Igniters

Table 3.3-1 summarizes the data on solid propellant motor igniters and gas generator igniters. Four programs (A1, B, H and I) utilized pyrogen igniters for motor ignition. Six programs (A2, C, D, E, F and G) used pyrotechnic devices. The igniters in programs J, K, L and M represent gas generator igniters.

These statistics are further summarized in Table 3.3-2 by three classifications: pyrogen solid rocket motor igniters; pyrotechnic solid rocket motor igniter; and gas generator igniters. Note in Table 3.3-2 that each classification contains two lines of data. The first line represents total unit storage hours and failures which would have failed mission requirements. The second line is a subset of this data which represents ballistic parameter tests with failures to meet original acceptance specifications.

The numerical data indicates the pyrogen igniter to be more reliable in storage than the pyrotechnic igniter. However, this data could be misleading. The four failures reported for pyrotechnic igniters were quality and handling related defects and included three broken wires and an electrical short caused by incomplete potting of a radiation interference filter assembly. Any of these failures could have occurred in the pyrogen igniters as well.

Long term storage does appear to affect pyrotechnic igniters more than pyrogen igniters. However, due to insufficient samples of failures, no conclusion can be reached at this time.

The gas generator igniters are essentially identical devices to the pyrotechnic motor devices except for size and pressure requirements. The data shows no gas generator igniter failures which would have failed the mission requirements. Six failures to meet original acceptance specifications were identified.

TABLE 3.3-1. IGNITER STORAGE DATA

Program	Application/ Igniter Type	No. of Units	Storage Hrs.	Accep. Spec. Failures	Simulated Mission Failures	Age of Units (Months)
A1	Solid Rocket Motor Igniter/Pyrogen	21	992,070	0	0	65
A2	Solid Rocket Motor Igniter/Pyrotechnic	74	5,007,070	2	2	93
B	Solid Rocket Motor Igniter/Pyrogen	34	1,542,490	0	0	62
C	Solid Rocket Motor Igniter/Pyrotechnic	65	2,490,030	-	0	52
D	Solid Rocket Motor Igniter/Pyrotechnic	13 23	314,630 769,420	0 -	0 0	33 46
E	Solid Rocket Motor Igniter/Pyrotechnic	38	1,040,980	-	0	38
F	Solid Rocket Motor Igniter/Pyrotechnic	51 31	2,198,760 1,527,160	1 -	0 2	59 67
G	Solid Rocket Motor Igniter/Pyrotechnic	102	5,007,070	2	0	67
H	Solid Rocket Motor Igniter/Pyrogen	74	473,770	-	0	9
I	Solid Rocket Motor Igniter/Pyrogen	878	23,526,075	-	0	37
J	Gas Generator Igniter	18	635,100	-	0	48
K	Gas Generator Igniter	86 40	4,075,590 2,346,220	0 -	0 0	65 80
L	Gas Generator Igniter	59	2,949,200	0	0	68
M	Gas Generator Igniter	129	6,640,810	6	0	71

TABLE 3.3-2. IGNITER STORAGE DATA BY MAJOR CLASSIFICATION

Classification	No. Units	Storage Hrs.	Spec. Failures	Simulated Mission Failures	Avg. Unit Age
Solid Rocket Motor Igniter					
Pyrogen	1007 (55)	26,534,405 (2,534,560)	NA (0)	0 (NA)	36 (63)
Pyrotechnic	397 (240)	18,355,120 (12,527,770)	NA (5)	4 (NA)	63 (72)
Gas Generator Igniter	332 (274)	16,646,920 (13,665,600)	NA (6)	0 (NA)	69 (68)
TOTALS	1736	61,536,445	-	4	-

3.3.1.2 Safe and Arm Devices

Table 3.3-3 summarizes the storage data on safe and arm devices. Programs A1 and A2 utilize inertial switches; Programs C and D manual switches; and Program N motor driven rotary switches.

The motor driven rotary switch shows a relatively high failure rate as compared with the other switches. These switches were the only ones tested in a separate test program from the igniter, arming and safing times were monitored. Nine of the failures were indicated as catastrophic. The 35 specification mission failures were failures to arm in the necessary time to meet mission requirements. One hundred twelve additional specification failures were identified which would have fulfilled mission requirements. These switches showed definite aging trends in arming and safing times.

3.3.2 Aging Trends

3.3.2.1 Successes vs. Age

A comparison of successes and failures versus age of the igniters shows no apparent trend. Failures were distributed fairly randomly by age, however no devices under 4 years of age failed. A definite aging trend was indicated for the motor driven device. The percent of successful tests show a marked decrease with the age of the unit. A possible aging trend is also indicated for the inertial S&A device. No trend was analyzed for manual rotary devices since no mission or specification failures were reported.

3.3.2.2 Performance Parameters vs. Age

Five of the missile programs were able to project aging trends for individual ballistic parameters using the static firings at acceptance testing as a baseline.

The pyrogen igniters showed the least change with age (less than 2%) for burn time, maximum pressure and average pressure. The burn time increased while the maximum and average pressures decreased. These trends are identical to

TABLE 3.3-3. SAFE AND ARM DEVICE STORAGE DATA

Program	Type	No. Units	Storage Hrs.	Accep. Spec. Failures	Simulated Mission Failures	Avg. Unit Age
A1	Inertial	21	992,070	0	0	65
A2	Inertial	74	5,007,070	10	1 (C)	93
C	Manual Rotary	65	2,490,030	-	0	52
D	Manual	13	314,630	-	0	33
	Rotary	23	769,420	-	0	46
N	Motor Driven	2016	65,104,320	147	9(C) 34 (S)	44
TOTALS						
	Inertial	95	5,999,140	10	1 (C)	87
	Manual Rotary	101	3,574,080	-	0	48
	Motor Driven	2016	65,104,320	147	9(C) 35 (S)	44

C = Catastrophic Failures

S = Specification Failures

those described for double base solid propellant motors in Section 2.0. The trends are attributed to the inherently unstable propellant decomposing with age.

The pyrotechnic igniters showed larger changes with age than the pyrogen motor igniters. Data from programs F and G were separated from programs A2, C and D due to the much larger changes. Program F utilized accelerated testing and the extrapolation to real time may be inaccurate. All of the programs show an increase in ignition delay with age (up to 500%). This increase is due to two factors: the change in igniter ballistic characteristics and a change in the solid rocket motor ballistic characteristics. Maximum pressure and time to maximum pressure decreased for the pyrotechnic igniters except for programs F and G which showed an increase in these parameters.

The gas generator igniters showed a decrease in the three parameters measured: maximum pressure, time to maximum pressure and ignition delay.

For the motor driven rotary safe and arm device, a large trend in increasing arming time was seen (approximately 13% increase per year).

3.3.3 Failure Modes and Mechanisms

Table 3.3-4 summarizes the failure modes experienced during the igniter static firing tests. Catastrophic failures are defined as failures to functionally perform and specification failures are defined as failures to be within original acceptance specifications.

The catastrophic failures were caused by quality and handling problems and were not related to age of the units. The nine specification failures were generally related to aging effects.

Table 3.3-5 summarizes the failure modes exhibited by safe and arm devices during tests. The failure of the inertial device was caused by a manufacturing defect. Specific failure causes were not given for the motor driven devices.

Table 3.3-4. Igniter Failure Modes

Catastrophic Failures

Pyrotechnic Igniters

2 units - broken wire in harness
1 unit - broken squib bridge wire
1 unit - igniter electrical circuit shorted by RIF screen

Specification Failures

Pyrotechnic Igniters

1 unit exceeded maximum peak pressure specification
2 units failed minimum ignition delay specification

Gas Generator Igniter

6 units failed lower circuit resistance specification

Table 3.3-5. Safe and Arm Device Failure Modes

Catastrophic Failures

Inertial S&A Device

1 unit - blocked switch movement due to improperly manufactured cover

Motor Driven S&A Devices

57 units exceeded mission arming time requirements

Specification Failures

Inertial S&A Devices

6 units exceeded maximum arming time specification
4 units failed minimum arming time specification

Motor Driven S&A Devices

147 units failed maximum arming time specification

3.3.4 Other Defects Identified

Table 3.3-6 lists other defects noted in the devices, however, none of these were detrimental to the device tests. As can be noted, these defects range from quality problems to handling problems to possible aging problems.

Table 3.3-6. Other Unit Defects

Igniters

6 units frayed wiring harness
28 units cracked cover plate
2 units rust present
3 units wiring harness damaged
2 units improperly installed igniter connecting cables
Twisted grains
Hot gas seal defective
Potassium nitrate depletion in igniter

Safe and Arm Devices

Screws loose on gear train of inertial device
Cover plate improperly placed
Improperly placed safe and arm decal on manual switch

3.4 Conclusions and Recommendations

The data analyzed for igniters and safe and arm devices indicated both random type and aging type failures. A considerable amount of data was analyzed on age related degradation. However, for a number of devices, the lack of a large failure sample tends to make the reliability predictions conservative. Until more data is available, it is recommended that the reliability prediction models in figures 3.2-1 and 3.2-2 be used.

The data indicated that the pyrogen igniters show less deterioration with age than the pyrotechnic igniters. Therefore, pyrogen igniters should be considered for all applications.

Missile system design should compensate for age changes in igniters performanced.

Surveillance programs to detect excessive aging of igniters are recommended.

3.5 Reference

The information in Section 3 is a summary of document number LC-76-OR2, "Igniters and Safe and Arm Device Analysis," dated May 1976. Refer to that document for details of data collection and analysis and technical description of the devices.

4.0 Solid Propellant Gas Generators

A typical solid propellant gas generator has the following principal components: propellant, hardware and igniter. The hardware may include the generator body, combustion chamber, hot gas outlet or mounting pad, filter, and relief valve. The igniter is included in Section 3.0.

The solid propellants are used in gas generators to provide hot gas as an energy source. They are used primarily for driving turbines or auxiliary power devices. Usually the flame temperature of gas generator propellants is appreciably lower than that of rocket propellants, so that the gas can be used in uncooled piping and uncooled machinery. This means that such a propellant usually contains more fuel and less oxidizer.

Two or more mixtures or types of fuel may be used in a single generator to create a specific pressure time profile. A common example, is the use of booster pellets at the start of the gas generator operation to overcome inertia of moving parts in the turbine.

The types of propellants used can be broken into two major classes: composites and double base.

The main ingredients in a composite propellant are a fuel and an oxidizer. Often these consist of crystalline, finely ground oxidizers dispersed in a matrix of a fuel compound.

The double base propellant contains unstable chemical compound, such as nitrocellulose or nitroglycerin, which are capable of combustion in the absence of all other material. This type sometimes called homogeneous propellants contains no crystals, but uses chemical fuel that contain enough chemically bonded oxidizer materiel to sustain combustion.

Most of the solid propellants contain from four to eight different chemicals. In addition to the principle ingredients (fuel and oxidizer), small percentages of additives are used to control the physical and chemical properties of the solid propellant. Additives have been used for the following typical purposes: 1) accelerate or decelerate the

burning rate (catalyst); 2) increase chemical stability to avoid deterioration during storage; 3) control various processing properties of propellant during fabrication (during time, fluidity for casting, wetting agent, etc.); 4) control radiation absorption properties of burning propellant; 5) increase physical strength and decrease elastic deformation; 6) minimize temperature sensitivity.

4.1 Effects of Prolonged Storage

Mechanical stresses from transportation and temperature extremes and repeated temperature stresses can have deteriorating effects on propellant properties.

Cracks, voids, and tearing in the propellant materiel are a major result of these environments. The primary cause for these defects in composite propellants are: the difference in the thermal expansion between the propellant grain and the motor body and inhibitors; and the temperature stress at the oxidizer-filler interface.

At low temperature, physical changes cause propellants to become hard and brittle, and thus very susceptible to cracking due to shock loads. When the propellant is in this brittle condition, expansion or other physical changes which occur as the temperature rises may cause cracking. The hardening of a case-bonded charge at low temperature may result in the charge coming away from the case. The repeated expansion and contraction with cyclic temperature changes cause deterioration of the charge.

The deterioration may get worse with increasing duration of exposure to a given set of ambient conditions, and may be accelerated at wider temperature extremes.

Tensile stress at the oxidizer-filler interface in composite propellants may lead to the formation of voids around the oxidizer particles. Once void formation has started, it propagates to the vicinity of neighboring particles to produce a band or region of these failures.

At high temperatures, chemical and physical changes in the propellant may cause a serious reduction in the value of

the coefficient of elasticity. The inhibitor may also deteriorate at high temperature. When the generator is fired, the charge may deform excessively or portions may even break loose. This can increase the burning area and pressure causing out of spec, pressure and burn times or even causing the case to burst. Portions of propellant which break loose can also block the gas nozzle tube and result in a catastrophic failure.

Humidity can sometimes accelerate this deterioration. Gas generators are normally provided with humidity sealing to prevent ingress of moisture to the propellant.

Cracks in the propellant will increase the burning surface areas, which increases pressure and cause out of specification conditions.

Double-base propellants are prone to the same types of deterioration as described for composite propellants with the exception of the void formation at the oxidizer-filler interface. The double-base propellant is a homogeneous mixture and does not have the solid oxidizers in the grain.

However, in double-base propellants, nitrocellulose decomposes slowly but continuously, releasing oxides of nitrogen. The rate of decomposition is accelerated by the presence of these oxides. Certain materiels called "stabilizers" can combine chemically with the oxides and remove them. The stabilizer does not prevent decomposition but retards the rate after it has commenced. This decomposition can create grain defects in the form of gas bubbles or cracks.

4.2 Reliability Prediction

The data collected to date shows no gas generator failure which would have failed the mission requirements. Since the data indicates that the motors are definitely deteriorating with age, a failure rate prediction based on the number of hours in storage would be meaningless. Therefore, reliability based on binomial confidence levels for the number of successes experienced was calculated.

No distinct difference is apparent at this time between composite and double base propellant units. More specification failures occurred in the double base propellant, however, these units showed the least ballistic parameter aging trends. Therefore, the specification failures are apparently a function of the particular program application.

Table 4.2-1 gives the gas generator reliability at 50% and 90% confidence levels. The estimates are conservative since no mission failures were experienced.

The variation in the reliabilities in Table 4.2-1 is strictly a function of the number of data samples available for each classification. The measured reliability for all the units was 1.000.

Based on each program analysis, the recommended service lives were given as 6 years for one unit and 12 years for the other two units.

TABLE 4.2-1. GAS GENERATOR RELIABILITY
(excludes ignition system)

RELIAB'LITY

50% Confidence		90% Confidence	
5 Yrs.	10 Yrs.	5 Yrs.	10 Yrs.
.991	.925	.972	.775

4.3 Data Analysis

Data from surveillance of three missile programs has been collected and analyzed. Out of 5,828,320 hours of unit storage, ballistic data from 116 static firings indicated 7 failures to meet original acceptance specifications. No catastrophic failures were reported. Analysis of the 7 specification failures by program personnel indicated that in each case, the gas generator was capable of providing sufficient gas pressure to perform its intended mission.

4.3.1 Data Classification

Table 4.3-1 summarizes the data on the gas generators. Program A utilizes a double base propellant while programs B and C use composite propellants.

The double base propellant shows more specification failures than the composite. However, the double base propellant data included units older than the composite propellants and most of the specification failures were in the older units. In addition, the double base unit is smaller than the composite units.

4.3.2 Aging Trends

4.3.2.1 Successes vs. Age

A comparison of successes and failures versus age of the gas generators was made. The double base propellant generator shows a definite aging trend beginning in units at age 9 years. No aging trend is apparent in the data for composite propellant generators, however, no data is available past nine years.

4.3.2.2 Ballistic Parameters vs. Age

The three missile programs were able to project aging trends for individual ballistic parameters using the static firings at acceptance testing as a baseline.

Program A shows a decrease in burn time, early pressure and the pressure time integral over the burn time. The late pressure however shows an increase. Two mechanisms can be postulated to explain these trends. As with the double base solid propellant motor, a slow decomposition of the fuel is experienced with age. This generally accounts for reduced ballistic pressure and burn time. Radiographic inspection of the gas generators in program A indicated cracked inhibitors and separation of the inhibitor from the propellant. For two units this resulted in erratic burning and abnormal pressures. The general increase in late maximum pressure could be a result of the breakdown of the inhibitor.

Program B (a composite fuel generator) shows an increase in burn time and a slight increase in early maximum pressure.

TABLE 4.3-1. GAS GENERATOR STORAGE DATA

Program	Propellant	No. of Units	Unit Storage Hours	Accept. Spec. Failures	Simulated Mission Failures	Age of Units (Months)	Avg Press/ Burn Time (PSI/Sec)
A	Double Base	58	2,902,480	5	0	25 to 135	450/35
B	Composite	18	579,620	1	0	34 to 53	1000/60
C	Composite	40	2,346,220	1	0	37 to 100	500/100
TOTALS							
	Double Base	58	2,902,480	5	0	25 to 135	
	Composite	58	2,925,840	2	0	34 to 100	

Decreases were experienced in late maximum pressure, minimum pressure, and the time to the 900 PSIG level.

Program C (also a composite fuel generator) shows almost opposite trends from program B. An increase in average pressure and time to early maximum pressure was reported while burn time and early maximum pressure decreased.

The composite solid propellant motor analysis indicated a general trend toward decreasing burn time and total impulse and increasing pressures and thrusts. Program B does not follow this trend.

Program C, however, did experience a decrease in burn time and an increase in average pressure. This trend may be partially explained by the radiographic tests which indicated separation of the inhibitor from the propellant grain. The decrease in early maximum pressure was attributed to relief valve opening at lower pressures.

4.3.3 Failure Modes and Mechanisms

Table 4.3-2 summarizes the failure modes and mechanisms experienced by the three programs. The two primary failure mechanisms identified were inhibitor aging and pressure relief valve aging. The effects of these aging characteristics were discussed in the previous section.

Other defects noted in visual examination of these devices included a slight amount of rust, loosening of a phenolic liner, and damaged moisture seals.

4.3.4 Program Data

4.3.4.1 Program A

Fifty-eight units were tested. Thirty-nine of the units were from 2 to 5 years old and nineteen from 8 to 11 years old. The five specification failures occurred in the older units.

4.3.4.2 Program B

Eighteen units were tested ranging in age from 3 to 5 years old. The one specification failure occurred in a unit 46 months old.

4.3.4.3 Program C

Forty units were tested. Four units were less than four years old while the remainder were from 6 to 9 years old.

TABLE 4.3-2. FAILURE MODES & MECHANISMS

PROGRAM A

Modes

3 units failed minimum burn time specifications and exceeded the late maximum pressure time function

2 units exceeded the late maximum pressure specification

Mechanisms

Cracks in inhibitors and separation of inhibitor from propellant grain were indicated

PROGRAM B

Modes

1 unit failed the minimum pressure specification

Mechanisms

No mechanisms were identified

PROGRAM C

Modes

1 unit failed the minimum pressure specification

Mechanisms

Special tests indicated a pressure relief valve opening at low pressures. Inhibitor separations from the propellant grain were also noted

The one specification failure occurred in a unit 78 months old.

4.4 Conclusions and Recommendations

The data analyzed for solid propellant gas generators indicated no failures which would have failed the mission requirements. Until more data is collected, it is recommended that the following reliability prediction be used for solid propellant units:

5 Year Reliability:	.991 at 50% confidence
	.972 at 90% confidence
10 Year Reliability:	.925 at 50% confidence
	.775 at 90% confidence

The data indicated no significant difference between the types of generators.

Missile systems design should compensate for changes in motor performance.

Surveillance programs have proven to be invaluable aids to detect excessive aging of propellants and to initiate early correction for maximum system life.

4.5 Reference

The information in Section 4 is a summary of document number LC-76-OR3, "Solid Propellant Gas Generator Analysis," dated May 1976. Refer to that document for details of data collection and analysis and technical description of gas generators.

5.0 Miscellaneous Ordnance Devices

This section contains storage reliability data and analysis on miscellaneous ordnance devices.

Non-operational hours, failures and failure rate information is summarized in Table 5-1 for the different devices. Detailed information was not available on the devices to assess failure mechanisms.

Failure 5-1 presents recommended failure rates for reliability prediction. The failure rates for explosive bellows, explosive bolts, explosive timers are considered conservative since no failures were reported for these devices.

TABLE 5-1. STORAGE DATA ON MISCELLAENOUS ORDNANCE DEVICES

Device	Storage Hrs. x 10^6	Failures	Failure Rate in Fits*
Electric Igniters	**516.5**	**10**	**19.4**
Explosive Actuators (one bridge wire)	**130.**	**1**	**7.7**
Explosive Actuators (two bridge wires)	77.1	0	<13.0
Explosive Bellows	65.6	0	<15.2
Explosive Bolts	16.3	0	<61.3
Explosive Motors (one bridge wire)	15.5	0	<64.5
Explosive Motors (two bridge wires)	8.4	0	<119.0
Explosive Switches (one bridge wire)	288.1	1	3.5
Explosive Switches (two bridge wires)	126.9	1	7.9
Explosive Timers	28.2	0	<35.5
Zero Impulse Bolt	1.08	0	926.0
Pin Puller	1.87	0	535.0
Surface Fuse	.59	2	3390.
Energy Generator	1.61	3	1863.

*Failures per billion hours

FIGURE 5-1. MISCELLANEOUS ORDNANCE DEVICE FAILURE RATES

λ_p (Device Failure Rate)

Device	λ_p
Electric Igniters	$.019 \times 10^{-6}$
Explosive Actuators	$.063 \times 10^{-6}$
Explosive Bellows*	$.015 \times 10^{-6}$
Explosive Bolts*	$.061 \times 10^{-6}$
Explosive Motors*	$.042 \times 10^{-6}$
Explosive Switches	$.005 \times 10^{-6}$
Explosive Timers*	$.035 \times 10^{-6}$
Zero Impulse Bolt*	$.926 \times 10^{-6}$
Pin Puller*	$.535 \times 10^{-6}$
Surface Fuse	3.390×10^{-6}
Energy Generator	1.863×10^{-6}

*Estimates considered conservative.

IHMR 72-209, 20 December 1972, Surveillance of Sparrow AIM-7E/E-2 Rocket Motors MK 38 Mods 0, 1, 2, 3 and 4 and Igniter MK 265 Mod 0; Craig A. Pfleegor, Naval Weapons Station, Indian Head, MD, AD 524733L, Confidential.

IHMR 73-215, 15 March 1973, 1972 Annual Report of the Fleet Surveillance Group, Naval Ordnance Station, Indian Head, MD, AD 525085, Confidential.

IHMR 73-238, 24 March 1974, Surveillance of Shrike AGM-45A Rocket Motors MK 39 Mods 3, 4, and 7 and Rocket Motor Mark 53 Mod 1, Andrew J. Adams, Naval Ordnance Station, Indian Head, MD, AD 529394, Confidential.

IHMR 73-239, 20 December 1973, General Surveillance of the Talos Booster Mark II, Mod 5, lots 13 and 14; John W. McInnis, Naval Ordnance Station, Indian Head, MD, AD 529496, Confidential.

lHSP 70-52, October 1974, Service Life Listing and Surveillance Status of Propulsion Devices and Auxiliary Power Systems, Naval Ordnance Station, Indian Head, MD, AD 532079, Confidential.

IHTR 404, 18 October 1974, Sidewinder AIM-9D, 9G, and 9H Missile Rocket Motor Mark 36 Mods 2 and 5 Type-Life Program: Final Report; Ray H. Bazil, Naval Ordnance Station, Indian Head, MD, AD 531781, Confidential.

TWR-8580, 20 January 1975, Reliability/Maintainability Assessment and Reliability and Failure Report for Minuteman Stage 1 RIP Motor Production Motor, W. L. Hankins, Thiokol/Wasatch Division.

TWR-8712, 20 March 1975, Weapon System 133 Monthly Reliability and Failure Report Minuteman III Third Stage Motors, W. L. Hankins, Thiokol/Wasatch Division.

lHMR 71-136, May 1971, General Surveillance of the Tartar/Terrier MK2 and MK3 Gas Generator Igniters MK 247 Mod 0, Edward P. Mayernik, Naval Ordnance Station, Indian Head, MD, AD 884681.

lHMR 73-234, 19 October 1973, Surveillance of Igniter Mark 272 Mod 0, Michael J. McCabe, Naval Ordnance Station, Indian Head, MD, AD 914597L.

lHMR 71-147, July 1971, Surveillance of Terrier Gas Generators MK9 and MK10 and the Igniter MK262, Rolland V. Elliott, Naval Ordnance Station, Indian Head, MD, AD 885591

lHMR 73-227, 31 August 1973, Surveillance of Terrier Igniter MK 192 Mods 0, 2 and 3, Michael J. McCabe, Naval Ordnance Station, Indian Head, MD, AD 914059L.

1HMR 71-146, July 1971, Surveillance of the Talos Hot Gas Igniter, Dennis W. Merchant, Naval Ordnance Station, Indian Head, MD, AD 885589.

1HMR 71-167, 11 January 1972, General Surveillance of Sidewinder AIM-9D/G Gas Generator MKG Mod 2, Rolland V. Elliott, Naval Ordnance Station, Indian Head, MD, AD 890911L

22402-0001-T0-00, 10 April 1974, Service Life Evaluation of the 7300-11 ARM/DIASRM SWITCH, TRW Systems Group, San Bernadino, CA.

BIBLIOGRAPHY

"Rocket Propellants," Francis A. Warren, Southwest Research Institute, San Antonio, Texas, Reinhold Publishing Corp., N. Y.

"Solid-Fuel Rocket Propulsion," J. E. Duboo, Temple Press Books, London

"Rocket Propulsion Elements," George P. Sutton, Rocketdyne, John Wiley and Sons, Inc., N. Y.

Advances in Space and Science Technology, Vol. 5, pgs. 48 through 55, "Solid Propellant Rocket Technology," H. W. Ritchey and J. M. McDermott, Academic Press, N. Y.

"The Chemistry of Propellants," Pergamon Press, N. Y. 1960

"Mechanics and Chemistry of Solid Propellants," Proceedings of the Fourth Symposium on Naval Structural Mechanics, April 19-21, 1965, Pergamon Press, N. Y.

ICRPG/AIAA 2nd Solid Propulsion Conference, June 6-8, 1967

0162-02MRF-142, 20 December 1974, Weapon System 133B Reliability and Failure Report, Contract F04701-73-C-0206, Aerojet Solid Propulsion Co.

ORDP 20-220, Ordnance Engineering Design Handbook, Propellant Actuated Devices, Office of Chief of Ordnance, Department of the Army.

IHMR 70-107, 3 June 1970, Rocket Motor Mark 12 Mod 0 (Terrier Booster) Type-Life 7.0-Year Summary Report; David R. Koster, Naval Ordnance Station, Indian Head, MD, AD 510239, Confidential.

IHMR 71-152, September 1971, General Surveillance of the Sparrow III AIM-7D EPU Gas Generator; Robert V. Elliott; Naval Ordnance Station, Indian Head, MD, AD 518119, Confidential.

IHMR 72-175, April 14, 1972, Surveillance of Tartar Rocket Motor, MK27 Mod 2, Daniel M. McCrae, Naval Ordnance Station, Indian Head, MD, AD 520539, Confidential.

IHMR 72-180, 12 June 1972, Surveillance Evaluation of 5.00-inch Zuni Rocket Motors MK 16 Mods 1, 2, and 3; James N. Blain, Naval Ordnance Station, Indian Head, MD, AD 902027.

IHMR 72-199, 15 November 1972, General Surveillance of the MK 37 Mod 0 ASROC Motor (reworked grain); John W. McInnis, Naval Ordnance Station, Indian Head, MD, AD 523590, Confidential